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The Control of Pollution from Hydrographic Modifications

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THE CONTROL OF POLLUTION FROM HYDROGRAPHIC MODIFICATIONS

UNITED STATES
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Washington, D.C. 20460

1973

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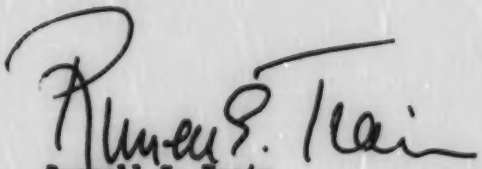
FOREWORD

Degradation of the quality of fresh surface and ground waters caused by hydrographic modifications such as stream channel alterations or the impoundment of water is a common problem as man alters his environment. Such pollution is frequently an unintentional result associated with these activities.

The Federal Water Pollution Control Act, as amended (33 U.S.C. 1251 et seq.; 86 stat. 816 et seq.; P.L. 92-500) requires the Administrator of the Environmental Protection Agency to issue information on the identification and control of pollution caused by hydrographic modification (section 304(e)(1&2)(F)). This report is issued pursuant to that legislative mandate.



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Preface

This report will present information including guidance for identifying and evaluating non-point sources of pollutants; and processes, procedures and methods to control pollution resulting from changes in the movement, flow or circulation of any navigable waters or ground waters, including changes caused by the construction of dams, levees, channels, or flow diversion facilities. This report is mandated in Section 304(e)(1)&(2) part (F) of The Federal Water Pollution Control Act Amendments of 1972, Public Law 92-500.

An examination of the U.S. Senate Committee on Public Works Report which accompanied S. 2770 and the Report of the Committee on Public Works of the U.S. House of Representatives which accompanied H.R. 11896 was made to guide the report preparation. This legislative history was used in conjunction with the specific language contained in the law. (Public Law 92-500).

The type of informational guidance and procedures intended by the Senate Committee are described as "...the impact on water quality of hydrographic modification work,..." (p.49). The term water quality is defined by the

Senate Committee are described as "...the impact on water quality of hydrographic modification work,..." (p.49). The term water quality is defined by the Committee as "...to refer to the biological, chemical and physical parameters of aquatic ecosystems, and is intended to include reference to key species, natural temperature and current flow patterns...", (p.51). Thus, changes in flow patterns through channal modification, reservoir construction and other projects must be identified and if possible, methods to reverse or alleviate damages described.

The descriptions in the House of Representatives Committee Report were not as extensive as the Senate Committee's discussion for this section. The report directs the Administrator to be "...diligent in gathering and distribution of the guidelines for the identification and the information or processes, procedures, and methods for control of pollution from such non-point sources as... natural and manmade changes in the normal flow of surface and ground waters."

The pertinent part of the Act reads as follows: Sec 304(e)

"The Administrator...shall issue...within one year...information including (1) guidelines for identifying and evaluating the nature and extent of non-point sources of pollutants, and (2) processes, procedures, and methods to control pollution resulting from...(F) changes in the movement, flow or circulation of any navigable waters or ground waters, including changes caused by the construction of dams, levees, channels, causeways, or flow diversion facilities."

Part (1) requires development of informational guidelines for the identification and evaluation of pollution effects. Such an evaluation does not require EPA to identify and evaluate but only to provide guidance for such. Part (2) requires identification of available processes, procedures and methods for relieving or ameliorating the pollution resulting from changes in flow induced by stream hydrographic modification. The Act does not require the EPA to evaluate such methods, but only to identify those potentially applicable to control pollution from such hydrographic modification.

In the process of developing this report, potential problems are identified for each hydrographic modification technique which may not be applicable to many areas of the

country or which may occur only infrequently. In comprehensively evaluating the pollution effects of a project, many factors must be considered that investigation ultimately determines do not affect the environment. Therefore, only a few of all possible detrimental factors may need mitigation for any specific project.

Section 304(e) of Public Law 92-500 also requires the publication of additional material for the control of pollution from hydrographic modification from time to time after the initial report is published. For some areas which are not addressed by this report or for which additional coverage is necessary, supplementary reports will be issued.

I. Guidance for the Identification and Evaluation of Channel Modification Projects

Introduction

The definition and purpose of channelization projects are to increase the flood flow conveyance capacity of water courses through rural or urban flood prone areas, or to facilitate the drainage of what may be considered excessive surface and ground water from lands which can be used as other than natural wetlands.

This discussion will be limited to aspects of channelization where actual in-channel modifications occur. Consideration of other aspects of channelization will be covered under separate headings such as reservoirs.

The type of channel envisaged in this discussion is the small stream which frequently floods either urban or rural areas causing significant damage. In general such streams would be too small for commercial navigation purposes but would be of recreational benefit for canoeing and other activities. Also included are those drainage projects used

to render low-lying lands usable for agriculture or construction of suburban developments.

Current Governmental Involvement

Various governmental agencies, private groups and individuals are involved in designing and constructing channelization projects.

The Federal agencies principally concerned with channelization projects on a whole basin scale or major portions of basins are the Soil Conservation Service of the Department of Agriculture, U.S. Army Corps of Engineers of the Defense Department, the Bureau of Reclamation of the Interior Department and the Tennessee Valley Authority. Other agencies that may be involved on a smaller scale include the Federal Housing Administration in the Department of Housing and Urban Development, Veterans Administration and Federal Highway Administration of the Department of Transportation.

Contacts with the major Federal construction agencies should yield listings of projects completed, under planning and/or design and those being requested by various local governments or private interest groups. Such contacts

should provide information about the major projects in a given State or planning area.

State and local agencies involved in channelization projects are more difficult to identify in this type of report because of the various names such organizations use from State to State and locality to locality. Often these agencies will be identified in project reports prepared by the Federal agencies as participants in a given project. Organization names frequently used include a State Soil and Water Conservation Committee, Soil Conservation District, Drainage District, Watershed District, Conservancy District, Flood Control District or Irrigation District. These organizations provide local support and frequently partial funding of projects constructed under the auspices of a Federal program.

State and local governments frequently are directly involved in the financing of projects either on a partial basis conjunctively with Federal Agencies or in totality for Federally ineligible projects.

Privately constructed projects are even more difficult to identify. Usually, these projects are small and limited

to one individual's or at most a few individual's property These projects would generally be for drainage purposes to make land usable for agriculture or housing development. However, the effects of such projects may cause significant water quantity and quality changes in a given area. These projects may be located by examination of Department of Agriculture aerial photographs, examination of construction permits, inspection of recently constructed housing subdivisions or by contact with large housing or heavy equipment contractors in a local area.

Current Practices

Current practices can generally be subdivided into those principally flood control oriented or those principally drainage oriented. In combined projects, design is frequently dictated by flood control requirements. Several alternatives are generally available to accomplish the goals of a given project. Current practice is generally to use the method with the least cost to obtain the design objective unless some compelling reason overrides the economic justification.

CLEARING AND SNAGGING

Clearing and snagging operations may be used as an independent technique for increasing channel hydraulic capacity or it may in essence be a maintenance technique for maintaining a previously improved channel. The basic operation is the removal of obstructions from the channel which impede flow directly, which increase hydraulic friction, or which present obstructions that accumulate debris carried by the stream during high water conditions and thereby reduce the available area of flow.

Clearing and snagging operations are frequently used following high water to remove accumulated debris, logs, rocks, etc. and restore the hydraulic capacity of the channel. Equipment used consists of bulldozers, front loaders, cranes, draglines, clamshells, chain saws, and winches to physically remove the obstructions.

Although less expensive than channel resectioning for increasing the hydraulic capacity, clearing and snagging is also less effective. For restoring hydraulic capacity in a channel it may be the most efficient technique. However, improvements may be short lived. In certain types of basins

channel obstructions can re-occur within relatively short spans of time.

CHANNEL EXCAVATIONS

Channel excavating is principally of two types. In many cases the existing channel is enlarged and reshaped to increase hydraulic capacity. In other cases the existing channel is abandoned and a new channel is excavated. New channel construction has frequently been used for irrigation canals where no previous channel existed.

The design configuration and construction of the channel excavations depends on the purpose and physical setting of the new channel. In urban areas where land values are high and flood damage losses high, channels are frequently designed with a rectangular configuration to minimize land requirements and are concrete lined to achieve maximum hydraulic efficiency. In rural settings channels may be designed wider with a trapezoidal shape. Side slopes are determined by soil stability or by the final covering used such as grass, rip-rap or other channel liners. In situations where channel resectioning has resulted in excessively steep hydraulic slopes that cause excessively high water velocities which erode the channel bottom or side

slopes, grade control structures are used at frequent points along the channel to dissipate energy. An erosion resistant lining such as concrete or rip-rap may also be used.

The technique selected for excavation varies with the project size, whether "wet" or "dry" construction is possible, and the method of disposing of the spoil. In "dry" construction situations conventional drag lines, power shovels, clam shells or front end loaders are used; in "wet" construction situations some method of dredging is usually employed. The dredging method used depends on the material to be dredged.

CHANNEL REALIGNMENT

The purposes of channel realignment are principally to increase the hydraulic conductance when sufficient capacity is unavailable from the natural configuration and to eliminate the meandering of the stream over the flood plain. Without proper design, meanders frequently result in instabilities which cause changes in the channel section and which result in poor hydraulic efficiency. By realigning the channel into a straighter and therefore shorter length, costs of a channel improvement may be reduced when compared with resectioning the existing channel.

Physical constraints on realignment are existing roads and bridges and the existence of available land for right of way. Other constraints include costs, stability and environmental damage. Channel realignment is complicated by the problem of excavated material disposal and the destruction of the fish and wildlife habitat available in the old channel. Frequently, these "oxbows" are intentionally maintained with sufficient flow or backwater to maintain the habitat.

FLOODWAYS

Floodways are flow areas which are constructed to convey floodwaters around a protected area. These flow areas may be formed by protective dikes or be a separate channel. Floodways are constructed in lieu of modification to the existing channel or in conjunction with channel hydraulic improvements.

Such channels are designed to be dry until the water stage in the stream reaches a predetermined flood level and then to convey (in conjunction with the existing channel) flows greater than this amount. When flood flows recede, water is diverted from the floodway back into the principal channel.

Floodways that cut-off meanders are shorter than the natural channel and have greater hydraulic efficiency. Flood stages up-and-downstream may be affected by the use of such supplemental channels.

Since floodways are dry during normal stream flows, they may be used for other purposes such as pasture or as parkland. Maintenance is required to remove new growths of trees and brush and to maintain grass cover to minimize erosion during flood periods.

A flood control project using floodway channels requires more land than a channel resectioning project because of the dual channels and is therefore more expensive. Maintenance costs also can be high. Maintenance cost include removal of regrowth in the floodway and if non-permanent overflow devices are used, replacement of these periodically.

The principal benefits as related to water quality are the preservation of the natural fish and wildlife habitat in the natural channel and the maintenance of the natural appearance of the stream.

RETARDING BASINS

A retarding basin consists of a dam with an ungated outlet. The discharge of water from the dam is related to the height of water stored in the reservoir.

The purpose of these structures is the temporary storage of storm water. The stored water is gradually released when the channel capacity exists to pass the flow. The stream hydrograph reflects a reduced stage of increased duration. Flooding downstream is consequently reduced.

Consideration of such structures as part of a project is influenced by actual construction costs, land acquisition costs and the existance of acceptable terrain. The use of these basins rather than channel resectioning is preferred and incorporated in basin drainage plans when feasible.

DRAINAGE DITCHES

Drainage ditches are included in channelization project planning but seldom dictate the design channel capacity. Channel capacity normally is controlled by flood flow conditions. Drainage ditch projects usually involve

deepening previously constructed ditches or in constructing new ditches.

Where ditches are used to lower the water table and enhance drainage, the dry weather stream flows may be reduced in the main channel if the ditching project covers a sufficiently extensive area. Some increase in main channel peak flows may occur because of better interception of surface run-off and the more efficient hydraulic conveyance of such run-off than previously existed.

The depletion of ground waters and subsequent reduction of stream flows can impair quality in both surface and subsurface waters. In addition to the reduction of fish and wildife habitat, there is a decrease in dilution water for organic materials and a modified seasonal water temperature pattern. Ground water infiltration tends to increase stream temperatures during the winter season and decrease stream temperatures during the summer-season.

Sources of Pollution

Following the initial vegetative recovery after the various channel modifications are constructed, both direct and indirect sources of pollution are identifiable.

Realizing that the main purpose of channelization projects is either to increase hydraulic capacity to convey flood waters thus protecting adjacent property; or to provide drainage of land to increase its economic usefulness, the effects in terms of environmental pollution are apparent.

SCOUR FROM BOTTOM AND BANKS

In order to enhance the hydraulic efficiency of channels by resectioning, realignment or even clearing and snagging, the channel roughness is reduced. Such a reduction in roughness decreases friction losses and thereby increases the velocity of flow. If the channel is not properly designed, the increased flow velocities may exceed the stability velocities of the bottom or bank materials and cause erosion or scour. This in turn degrades the channel and furnishes sediment for stream transport, destroys natural habitats and detracts from the aesthetics of the stream.

Perhaps the worst offender in this regard is channel straightening and realignment. This process reduces channel lengths but not the decrease in elevation over which the water is lowered in traversing a stream section. The net result is a substantial increase in the stream gradient with

resulting substantial increases in stream velocities. Without extensive control measures for stabilization and the use of grade control structures, channel degradation can be extensive.

INCREASED POLLUTION FROM THE USE OF FLOOD PROTECTED AND DRAINED LAND

Following the implementation of both flood control and drainage projects, extensive amounts of land become available for higher economic production. Land formerly used for pasture or low return agricultural crops can be converted to high yield agricultural crops. Within municipal areas, property values are increased and uses with more economic return can be developed. With the increased land use there is potentially environmental degradation.

Enhanced agricultural use is accompanied by increased fertilizer, herbicide and pesticide use and by increased land tillage which may increase the erosional soil loss. The by-products of this agricultural use drains to the stream and causes various amounts and kinds of water quality impairment. The kind and amount of such pollutants entering the stream would be determined by the soil type, land slope and cropping practice.

Channelization projects which provide flood protection within urban areas frequently include the provision of lined channels. The effects on the water environment of these channels are both the destruction of fish and wildlife habitat and the destruction of aesthetic qualities.

ELIMINATION OF FISH AND WILDLIFE HABITAT AND AESTHETIC QUALITIES

The various channelization practices have varying effects on fish and wildlife habitats. In general, the more extensive the modification structurally the more damage is caused to habitat areas. For example, concrete lining of channels eliminates habitat areas for practical purposes whereas at the other extreme, clearing and snagging may not have a detectable effect. The effects of the project can only be determined by the use of before and after surveys designed to detect both drastic and subtle changes.

Aesthetic values for streams depend a great deal on the beholder. Swamp habitats may be quite disagreeable to a non-naturalist whereas parkland or pasture beside an improved channel may appear quite pleasing. To this extent aesthetics may be an acquired attribute in conjunction with strictly innate appreciation. Aesthetics is the most

difficult environmental factor to quantify and it may require the opinion of a representative cross section of the population before classification of a project as aesthetically acceptable.

Types of Pollutants

This discussion will be limited to the common pollutants both contributed directly and indirectly. Such pollutants are the common denominators to be anticipated from the majority of projects.

DIRECT EFFECTS

Sediment

Sediment is perhaps the most ubiquitous of all pollutants associated with channelization. The most pronounced effect on sediment occurrence and concentration is during the construction phase of the project. With bare soil banks and a non-stabilized channel, the natural stream flow itself and any rain that occurs flushes sediment into the stream discoloring the water and making it turbid. Following stabilization however, the stream frequently remains more turbid than before the project was constructed.

Every stream has an ability to naturally transport certain amounts of sediment. The amount transported is termed sediment load and is a definable stream characteristic. When channel hydraulic characteristics are changed by constraining the channel to a fixed location, by realignment, or by other means, the velocity of water flow is changed and consequently the ability to transmit sediment is likewise changed.

The effects of increased sediment on water quality are to reduce light penetration, to periodically blanket fish spawning areas, to periodically blanket and suffocate aquatic insect larvae used by fish as food, to create shoaling and instabilities in the channel itself, and to cause problems with sedimentation in unimproved channel sections downstream from the project section. In addition to these problems which directly affect instream water quality, increased costs are realized by water users including water suppliers and irrigators. Additionally, aesthetic quality is reduced to a substantial degree.

Thermal

The design of channelization projects for flood prevention requires increased channel dimensions. Because

of the enlarged channels, the dry weather flow is directed near the center of the channel. The stream flow is thus deprived of shade provided by trees along the banks and is exposed to solar radiation which heats the water. Previously in the natural channel, the presence of such trees along the banks provided shade for the flowing water and helped moderate stream temperatures.

In addition to reducing temperatures during daylight hours, the insulating effect of these trees is removed and night time temperatures are reduced to a greater extent than previously. Thus, a greater diurnal variation in temperature can result from a channelization project.

The temperature effects on fish and other aquatic life are caused by both the absolute temperature itself and the temperature variation. Both increased maximum temperatures and increased variation can have detrimental effects on fish and other aquatic life during various stages of their life cycle. Specie selection, availability of food, attendant life cycle chemistry and water quality changes are all phenomena that are temperature affected.

Water quality is directly affected by increased temperature. Dissolved oxygen is removed more rapidly by

temperature. Dissolved oxygen is removed more rapidly by temperature-mediated bacterial oxidation of soluble and suspended organic materials. This problem is compounded by the reduced solubility of oxygen at higher temperatures so that a resulting decline in stream dissolved oxygen concentrations results. Decreased dissolved oxygen concentrations stress aquatic life dependent on this constituent.

Movement of Pollution Effects Downstream

In channel relocation or realignment projects where channel lengths are substantially reduced, the effect of increased water velocity can be pronounced. One effect of increased velocities on surface water quality is to increase the length of stream affected by pollutants whose effects are time dependent. The organic materials in discharged wastes and the drainage of natural organics from swampy areas along the stream are bacterially degraded and oxidized in the course of moving downstream. With an increased water velocity these materials move much farther in distance for the equivalent period of time required for completion of the biochemical reactions. Thus the effects of reduced dissolved oxygen levels extends farther downstream than previously.

In the case of dissolved oxygen the effect of extending the reaction over a greater channel length may be beneficial. The increased water velocity also increases reaeration which counteracts the decrease in dissolved oxygen concentrations caused by biochemical oxidation reactions. This effect may be sufficient to prevent dissolved oxygen concentrations from decreasing to previous low levels and thereby enhance water quality.

In contrast, the effects on feces-associated bacterial levels downstream from a discharge would be to expand the distance over which a health hazard would exist. The die-away reaction for these bacteria is also time related. The extension of such a health hazard is detrimental to water quality.

Increased water velocities also are capable of transporting increased sediment loads which may be deposited in non-channelized areas downstream. The phenomenon of sediment deposition tends to migrate upstream clogging channels and defeating the channelization improvement unless removed during maintenance operations.

In addition to simply transporting more sediment, increased velocities will, if large enough, make streams

more aggressive in eroding channels and stream banks which destroys much of the usefulness of the stream for other purposes.

Fish and Wildlife Habitat Alteration

Almost any modification of a channel alters the existing habitat for fish and wildlife. Not all such changes are detrimental however, provision of water storage for example may provide increased habitat areas but perhaps for a different than pre-project biological assemblage.

Most in-channel modifications do remove obstructions that are used by fish for protection from predators, for fish food habitats and for backwater breeding areas. Removal of trees and brush along stream banks removes protective cover and food sources for various water-related wildlife.

Many of these effects can be mitigated by incorporating proper factors into project design. For example, maintenance of water in cut-off oxbows helps retain available fish and wildlife habitats.

INDIRECT EFFECTS

Destruction of Aesthetics

Channelization projects have frequently been criticized for the destruction of aesthetic values of natural streams. The creation of geometrical shaped channels with highway-type alignment is not conducive to aesthetic appreciation by naturalists or the general public. It is possible to mitigate much of the aesthetic destruction by use of proper design techniques. For example, those techniques which only alter one stream bank or which provide a replanting program to establish vegetation similar to that existing prior to construction can be used. Other similar measures can be included to minimize the reduction of aesthetic values.

It should be mentioned also that aesthetic values can be enhanced for many people by various channelization-related projects. In many instances public accessibility to water courses is improved and parks or other recreation facilities can be incorporated into the right-of-way acquired for the project.

In-stream techniques can also be applied to maintain fish and wildlife habitat. Construction of pool and riffle

areas is one technique available. Use of more natural alignment and other design features are available to project planners.

Hydrology

Many of the effects on basin hydrology of a channelization project can be anticipated. The major effect is to increase the hydraulic capacity of the principal channel and the smaller channels which drain into the principal channel. The principal effect of this change is to move water more rapidly through the channel. Downstream from the channelization project these increased flows may cause increased flooding by shortening the time of concentration of peak runoff following heavy rains.

Drainage projects may aggravate this problem by allowing higher valued operations on the drained land. If the higher valued use is urbanization, then the paved areas, including roof areas, drain water to storm drains which convey water to the water course even more quickly than previously occurred and increase peak flow rates and subsequent flooding.

Drainage facilities also tend to lower the water table during wet periods of the year and deprive streams of the critical base flow required during dry weather periods of the year.

Methods of Pollutant Transport

The methods of pollutant transport in channelized stream basins are essentially the same as in the unaltered stream basin. Certain transport mechanisms are either increased or decreased by the effects of the alteration.

SEDIMENT LOAD

As indicated previously, sediment load is the amount of sediment characteristically carried by a particular water course. It consists of suspended and bedload sediments. Bedload sediment is sediment that is transported in a stream by rolling, sliding, or skipping along the bed very close to it; that is, within the bed layer. Sediment load is related to several factors but principally the hydraulic characteristics of the stream and the soil and geologic characteristics of the stream channel and drainage basin.

The effects of a channelization project is generally to cause an increased amount of sediment load. Improved hydraulic conveyance produces increased water velocities which in turn increase sediment transport capability. If the streambed is improperly stabilized following construction, this increased sediment load can be dramatic. Even though proper stabilization techniques are used, concentrations of sediment generally increase except in the special case of complete channel lining with concrete or other paving materials. Downstream from the channelization section, these materials can settle and fill the channel with excess sediment destroying hydraulic efficiency and stream biology and increasing the potential for stream meander formation.

Indirect effects of channelization are to enhance land for higher economic uses such as increased agricultural production or urban and commercial development. Many of the pollutants generated by these new uses become adsorbed with soil grains. Such organics as pesticides are particularly susceptible to such adsorption. When these soil particles are flushed into the stream, the adsorbed materials are likewise carried along for later deposition downstream. Following such deposition, these materials can enter the life cycle of the stream. Biological concentration in the

aquatic food chain may cause significant ecological disturbances.

The increased sediment load can be visible as increased turbidity of the stream water. The principal effect is to decrease the aesthetic value of a stream. On larger streams used for water supply purposes, increased turbidity causes increased treatment costs for potable or industrial water users.

Excess channel scour can cause increased sediment loads and downstream deposition, adsorbed pollutant transport, and direct detrimental effects to water suppliers and stream aesthetic values.

DIRECT DRAINAGE

The increased uses of land adjacent to streams following the provision of flood protection and drained arable land provide sources of pollution which directly drain into the water course. Many of the pollutants arise as the normal product of urbanization or farming practices. Others arise because of the removal of natural mechanisms which trap contaminants directly or provide detention time for the adverse effects to decay to acceptable levels.

With time, many pollutants are degraded into innocuous substances. Nature provides detention time in natural backwaters and in sluggish meandering streams. Pollutants in solid form or which naturally flocculate and settle are assimilated and may be destroyed in the bottom sediments by microbiological activity. Phosphorus is chemically removed as an insoluble salt while nitrogen and sulfur compounds are removed by conversion to gaseous forms which evolve to the atmosphere. Following channelization and drainage projects these natural places of detention are by-passed or removed which has the effect of increasing pollutant concentrations in the flowing waters. The effects of these pollutants are then transferred downstream decreasing water quality while in passage.

SOLAR RADIATION

The light provided by the sun provides the energy for the biology of natural waters. The so-called "food web" begins with primary production by algae which are capable of photosynthetic production and continues up through the consumer species including aquatic insects and fish. Too little solar radiation produces too few algae, little primary production, and sparse fishery. Too much sunlight heats the water, provides a competitive advantage for

undesirable biological species and an unsatisfactory fishery. The effects of solar radiation are both on the water quality itself and on the biological response and effects to that water quality.

In many streams light penetration extends essentially to the stream bottom and provides energy for attached algae which provide both food and oxygen for animal life. In streams characterized by alternating pool and riffle areas, these productive areas are near the edge of the stream extending toward deeper water until the incident light is extinguished to less than photosynthetically usable levels. Following channelization, the stream channels are frequently made deeper reducing light penetration from former levels. Thus the habitat is altered and a different biological assemblage develops. Frequently, the new assemblage is composed of less desirable species.

Thermal effects become evident when shade trees and brush are removed allowing both more time and increased surface area of exposure to sunlight. Coldwater species of fish can not tolerate the elevated water temperatures and are replaced by warm water species. The direct effect of increased solar radiation may indirectly change the stream fishery.

Magnitude and Variation

Available statistics for defining the national magnitude and variation of channelization projects indicates that perhaps 200,000 miles of waterways have been altered in the last 150 years in the United States. Since the initiation of Federal projects in the early 1940's planning for and development of about 34,240 miles of waterways in 1,630 projects have been initiated under the Federally-assisted local protection and small project programs of the U.S. Army Corps of Engineers and watershed programs of the Soil Conservation Service. Additional projects have been initiated by the Bureau of Reclamation, the Tennessee Valley Authority and other Federal, State and local agencies.

The Corps of Engineers have assisted in 889 projects of which 47 percent involve channelization and 53 percent involve levees. Of these projects 6,180 miles (56%) are completed, 3,896 miles (35%) are under construction and 1,001 miles (9%) are planned. The median size for these projects is about 4 miles with two thirds under 5 miles and 80 percent less than 10 miles.

The Soil Conservation Service assisted in 558 projects of which virtually all involved channelization. Of these

projects 4,209 miles (25%) were completed by 1971 and 12,426 miles (75%) still remaining to be completed. The median size of the projects is about 18 miles with 38.7 percent less than 10 miles and 24 percent less than 5 miles.

COUNCIL ON ENVIRONMENTAL QUALITY REPORT

The Council on Environmental Quality's report (Ref. 1) discusses 42 different projects of 4 different Federal agencies. Each project was analyzed among other things for the basis of project formulation, physical effects of the completed project and the biological effects on the aquatic and terrestrial systems. The methodology used in preparing this report is an excellent guide for those evaluating additional projects.

ENVIRONMENTAL ASSESSMENT REPORTS

Since the enactment of the National Environmental Policy Act of 1969 (Public Law 91-190) each Federal agency participating in a proposed channelization project that significantly affects the quality of the human environment must prepare an environmental impact statement. These statements must assess the following for the project: (Title 42 U.S.C., Sec. 4332)

"(i) the environmental impact of the proposed action

(ii) any adverse environmental effects which cannot be avoided should the proposal be implemented

(iii) alternatives to the proposed action

(iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long term productivity, and

(v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented."

In accordance with NEPA all proposed projects significantly affecting the environment have such reports prepared. These reports are made available for review and comment in draft form. Final reports incorporating comments of reviewers are submitted to CEQ and are available upon request from the preparing Federal agency.

The environmental effects of a project are comprehensively covered in these reports. Whether or not the agency is able to mitigate the adverse effects identified in the environmental assessment, discussion of these effects is included. For most projects these assessments are invaluable in evaluating a project.

It should also be pointed out that several States have also enacted statutes patterned after NEPA which require an environmental impact statement before the expenditure of State funds or in some cases before permits are issued to private interests for project construction.

Prediction Methods

Methods to predict the effects of channelization projects will not be directly presented in this report. A tremendous volume of literature exists discussing the effects on water quality caused by various physical modifications of streams. Several sources of information will be mentioned as convenient and comprehensive starting places for project evaluation including the mitigation as much as possible of the inevitable adverse effects.

The CEQ report on channel modification (Ref. 1) presents the results of extensive biological investigations conducted by the Philadelphia Academy of Natural Sciences. Chapter 5 of Volume I of this report entitled, "Effects of Channel Modifications on Fish and Wildlife Resources, Habitat, Species Diversity, and Productivity" directly addresses the biological effects observed in 21 channelization projects analyzed. The same or similar effects therefore are to be anticipated in other projects under comparable conditions. Discussion includes the effects of channelization projects which cause erosion, consequent sediment accumulations and unstable stream beds, remove solid substrates, or decrease light penetration which may affect the biological population by disturbing the number of species, the populations of each, or the productivity of the stream, and alternatives to channel construction which will avoid adverse effects altogether.

Methods to predict the effects of channelization projects are included in a volume produced by the Soil Conservation Service entitled, "Planning and Design of Open Channels" (Ref. 2). This document comprehensively presents available information on channel design including the estimation of anticipated flows; location, alignment and hydraulic design; and channel stability design. A recently

auded chapter 7 (1971) includes environmental considerations. The technical methodology presented in this document is sufficient to predict the effects of the hydraulic changes caused by a channelization project including any increases in sediment transport.

Increases in the stream temperature and the diurnal variation are not so readily predicted. These calculations can only be made by estimating the amount of protective shade removed, changes in depth and changes in channel length in conjunction with tables of solar radiation values. Such calculations will probably only yield approximate semi-quantitative amounts of change.

The best technique for evaluating potential effects of channelization on a stream is the field survey of a nearby stream which has undergone the changes projected for the stream of interest. Comparison of this type of information establishes a more rational basis for predicting the various physical, chemical and biological changes to be anticipated. In the absence of such a situation, predictive techniques from the sources suggested above and in the companion report entitled, "Methods, Processes and Procedures to Control Pollution Resulting from Channel Modification Projects" are available for use.

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II. Methods, Processes and Procedures to Control Pollution Resulting from Channel Modification Projects

This discussion will be limited to those design changes in the actual channel modification project that can be incorporated to enhance and mitigate undesirable by-products. A brief discussion will be directed to consideration of alternatives to channel modification such as flood plain zoning regulations. Discussion of other structural alternatives including upstream storage reservoirs are covered under separate headings.

Design Modifications to Minimize Adverse Channelization Impacts

CHANNEL ALIGNMENT

Channel improvement projects generally are designed to follow existing stream alignment with the exception of situations where stability or cost factors force an alternative course. Also, changes are often made to provide larger parcels of flood free land. In stream sections passing through highly erodable soils for example, an

alternative course may be desirable if an alignment through more stable soils exists. Relocation may also be desirable to avoid passage through otherwise valuable lowland areas which serve as fish and wildlife habitats.

In the design for channel construction the alignment generally should follow a natural pattern which should consider the type of existing stream, the required hydraulic capacity and comparison with upstream and downstream sections of the particular water course or a similar nearby water course. The use of such design techniques avoids the unnatural appearance of a modified channel thus improving aesthetic appeal. In many cases such design may aid channel stability by not changing the channel gradient excessively.

Special features along the stream should be protected to enhance aesthetic appeal. By proper design of channel alignment the existence of particularly striking features can be preserved and perhaps enhanced which adds to the public appreciation of the projects. Design should incorporate provisions to protect these features including

special stream and streambank stabilizing measures, land treatment methods and grade adjustments.

CHANNEL CAPACITY

Channelized streams should convey water discharges ranging from base flow to the design flood flow without damage to the channel itself. The low flow channel cross section should approach the natural stream condition. The bottom width and side slopes can be designed to simulate the natural channel so that it will blend with upstream and downstream sections of the natural channel and avoid a monotonous appearance. At bends, the channel side slope can be steepened on the outside of the channel bend and flattened on the inside to simulate natural waterways. Use of naturally occurring rocks and boulders can be placed at selected points for aesthetic appeal, energy dissipation and fish-habitat development. The bottom width of the channel can be varied in conjunction with the channel slope to develop pool and riffle areas to aid fish and wildlife yet maintain hydraulic capacity. The use of rip-rap made from native rock improves the aesthetics, offers hiding places for crustaceans, small fish and other aquatic biota, and gives the banks and channel bottom stability in an otherwise erosive channel. Inclusion of these devices however

requires the careful attention of the designer, the on-site inspection personnel and especially the contractor.

CHANNEL GRADE

Within the topographic constraints of a given project, the channel gradient can be varied between stream reaches to achieve naturally appearing pool and riffle areas, cascades or other such features. To accommodate the existence of highly erosive soils in certain reaches, gradients can be flattened. Conversely, in erosion resistant soils gradients can be steepened. All such changes must remain within the natural topographic constraints of channel elevations at the beginning and end of channel sections. The use of such grade variations not only enhances aesthetic appeal but increases protection against meander development, increases channel stability and minimizes sediment from channel and bank erosion.

Adjustment of the channel gradient to develop pool and riffle areas can also provide increased atmospheric reaeration capacity in the stream. Reaeration increases with increased velocity and decreased stream depth. Riffle areas provide additional turbulence which also tends to increase reaeration. The increased dissolved oxygen

supplied by the increased reaeration improves the habitat for fish and aquatic life. It also provides additional capacity to satisfy the demands exerted for the oxidation of naturally occurring or man-contributed organic material before damage to aquatic life occurs.

SPOIL PLACEMENT

The on-site placement of excavated spoil material should be accomplished so as to minimize the amount of clearing required or other land disturbing activities. Spoil should be placed in such a fashion so as to minimize the potential for the erosion of the material back into the stream. Placement of spoil should also be made so as to minimize the adverse effects on wildlife habitats and may be concentrated at selected locations along the stream section to accomplish this goal. Through proper re-vegetation and planning the spoil may be used to create scenic overlooks and other contrasting features which may enhance the aesthetic appeal of a project and avoid the monotony of continuous spoil banks beside the stream.

The amount of spoil can also be minimized by the use of one-sided or single stream bank construction where appropriate (Figure 1). Other spoil reducing measures can

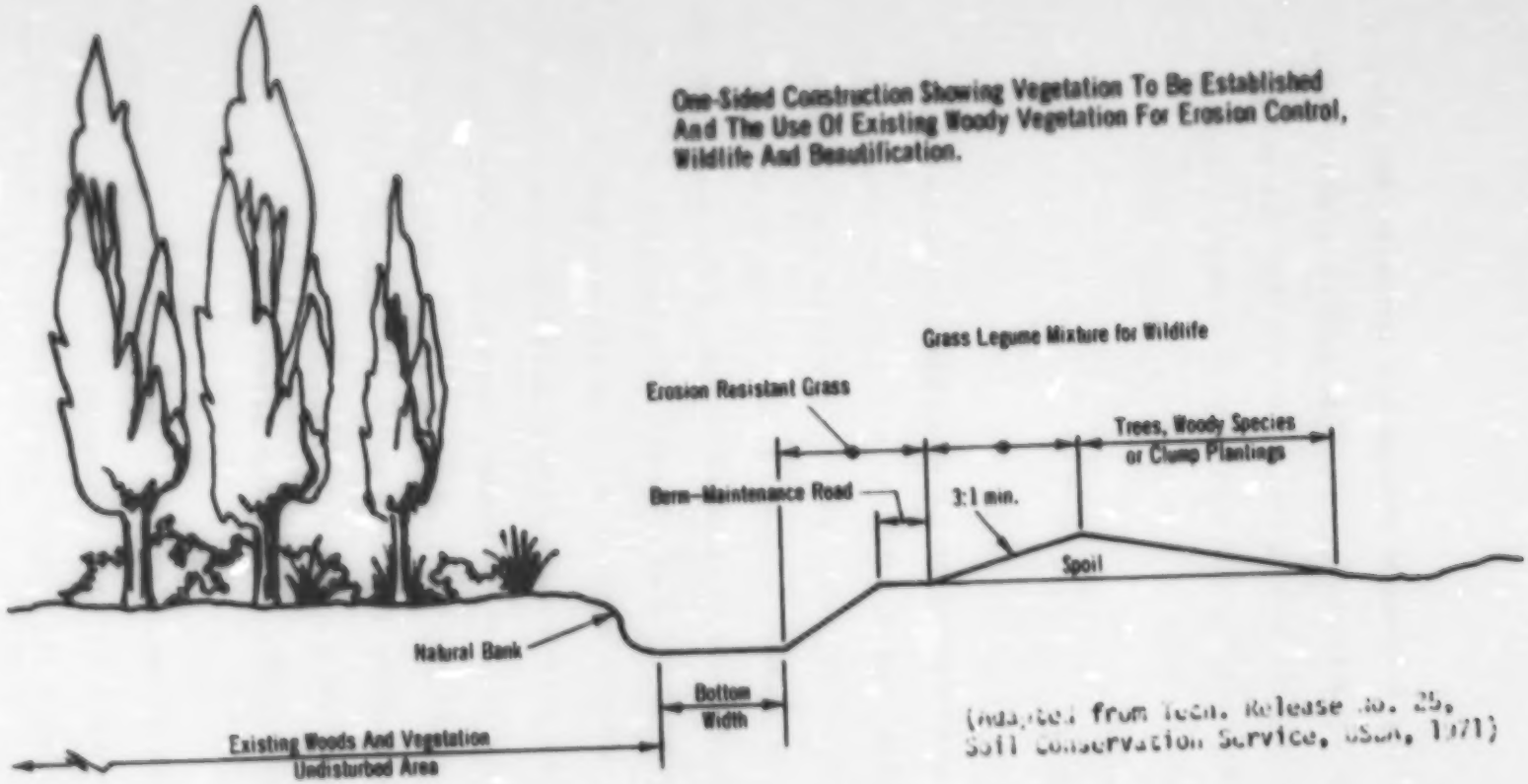

One-Sided Construction Showing Vegetation To Be Established And The Use Of Existing Woody Vegetation For Erosion Control, Wildlife And Beautification.
Grass Legume Mixture for Wildlife
Erosion Resistant Grass
Trees, Woody Species or Clump Plantings
Berm-Maintenance Road
3:1 min.
Spoil
Natural Bank
Bottom Width
Existing Woods And Vegetation Undisturbed Area
(Adapted from Tech. Release No. 25, Soil Conservation Service, USDA, 1971)

Figure 1 One-sided Channelization Construction

be included by the use of non-structural alternatives totally or partially in lieu of actual channel modification.

STRUCTURAL MEASURES

Structural measures can be included in a channel modification project to maintain stability by alleviating problems of excessive grade. Structural measures can also be applied to side stream entry points to control the introduction of sediment, debris or other pollutants or effects.

For channels with excessive slopes which would otherwise erode and produce sediment, typical structual measures include drop structures, chutes, steepened rock-armored sections and cascade structures. Each of these structural modifications provides resistance to high velocity flows and allows the use of stable, moderate gradients upstream and downstream.

For channels with sufficiently flat gradients so that channel and bank stability are not problems, designs can be incorporated using the pond, riffle and pool sequence. The inclusion of ponding provides sufficient excess elevation that succeeding pool and riffles can be maintained. Besides protecting fish habitat, aesthetic appeal is increased (Figure 2).

Side channel structures include pipe drops, lined chutes and drop spillways. These structures can be used in conjunction with sediment basins and debris traps to retard the input of these materials into the main channel. The principal purpose of these structures is to prevent the loss of vegetation from stream banks at the point of entry, slumping of the main channel bank or the cutting of a deeper tributary channel. All of these effects contribute sediment to the main channel and reduce channel stability.

CHANNEL PROFILE - BUILT IN GRADE AND BOTTOM CONFIGURATION

(Adapted from Tech. Report No. 25,
Soil Conservation Service, USDA, 1971)

Figure 2 Channel Profile - Built In Grade and Bottom Configuration

VEGETATION

The early re-establishment of vegetative cover following in-channel modifications is most important to prevent extensive erosion and damage to the hydraulically improved channel. The selection of the plantings should incorporate both an initially quick growth to stabilize the bank and the subsequent development of a cover which will blend with or simulate the natural cover.

Use of proper erosion resistant cover will keep sediment concentrations and adverse water quality impacts to a minimum. Proper selection of trees and bushes will enhance biological productivity within the stream itself and the associated wildlife. Shade provides against excessive solar radiation which helps maintain temperatures within allowable tolerances and insulate against excessive diurnal thermal variations.

Use of acquired right of way for parks, hiking paths or the provision of access for fishing is also enhanced aesthetically for public use by the use of suitable re-vegetation practices.

EFFECTS ON GROUND WATER

Any channel modification may alter the natural circulation of the ground water. Natural recharge to the ground water may be increased or decreased depending upon location, depth, and other characteristics of the new channel. Thorough investigation of possible effects on both the quantity and quality of ground water should be made before undertaking a channelization project.

An important distinction in terms of their effect on ground water quality is whether channels are lined or unlined. A lined channel, constructed of an impermeable material such as concrete, may prevent the natural interchange of streamflow with ground water. Such a lining may be required to provide flood protection in an area with unstable soils.

In areas where such recharge is important, water can be artificially recharged to the ground water. This can be done by installation of ditches or basins for artificial recharge in the vicinity of the lined channel. High-quality water diverted from the stream or derived from some other source and released into these structures would infiltrate

to the ground water and thus compensate for the loss of natural streambed recharge.

In unlined channels, a primary effect is that produced by changing the water table elevation in the area adjacent to the channel. If a channel is dredged in an area where the water table is close to the land's surface, the new channel acts as a drain and lowers the water table. If the water table elevation needs to be maintained at pre-channelization levels, the effect of lowering the level can be negated by lining the channel with an impermeable material. This will prevent dewatering of the upper portion of the aquifer and hence maintain the original natural conditions of ground water quality. Some drainage to prevent uplift of the channel lining may be necessary.

There may be some loss of bank storage of water even with unlined channels if the hydraulic characteristics are improved and the gradient steepened, resulting in higher velocities. The effects on ground water quality are the same as for lined channels. Artificial recharge can be used to compensate for the loss.

Unlined channels may allow polluted water to enter the ground water if there is no impermeable barrier between the bottom of the channel and the ground water body.

In some coastal areas natural channels have been deepened or new channels excavated. These have sometimes cut deeply into or through the underlying clay formation which originally acted as a natural barrier and prevented the downward movement of saline water into the underlying freshwater aquifers. Serious ground water pollution has resulted. Such channels should be located, designed, and constructed with care so that the natural barriers to saline water intrusion will not be impaired. If this is not possible, the channels must be artificially lined.

Structural Alternatives to In-Channel Modifications

In many cases in-channel modifications can be reduced substantially or avoided altogether by the use of various alternative designs involving construction of off-stream facilities. Such facilities as levees, floodways, retarding basins, building flood proofing and land treatment can be incorporated into projects to avoid actual channel modification.

LEVEES

Levees are generally low structures located along the edges of surface water bodies such as rivers, reservoirs, lakes, and the sea to prevent inundation of land behind the levees during periods of high water levels resulting from floods, storms, or tides. Levees also may be constructed to form a controlled channel. A floodwall serves the same purpose as a levee but is constructed of concrete or masonry to save on right-of-way acquisition. Only in rare instances do levees or floodwalls extend deeply enough into the subsurface to form a barrier to ground water flow.

In coastal areas levees prevent the flooding of land by seawater. As a result, the quality of ground water in the aquifers behind these levees is protected.

Occasionally a harmful effect of a levee on ground water quality may occur in floodplain aquifers near streams. The dissolved mineral concentration of most floodwaters is lower than that of ground water. During periodic inundations of floodplains, some of the water infiltrates to the floodplain aquifer and acts to improve its quality by dilution. Where a levee prevents this action and reduces the natural recharge, the mineral quality of the aquifer

will tend to change with time. The existence of such localized flood plain aquifers is confined to special geological situations and is not a common problem throughout the country.

The effect on surface water quality of levees located along a channel is principally the encouragement of erosion and channel scour during high water periods which contribute sediment and increase water turbidity. Since the stream is confined by the levee to a smaller than natural flood channel, water velocities are increased above natural conditions causing channel scour. The increased scour can subject underlying less resistant geological formations to attack and perhaps even breach aquitards opening aquifers to pollution by contaminated surface waters.

Control methods include use of wider spacing between levees to provide additional area of flow and the use of stabilization techniques on the levees themselves and in the flood plain such as plantings or rip-rap. Levee maintenance is important to continue both the protection against floods and to reduce the production of sediment caused by erosion and scour.

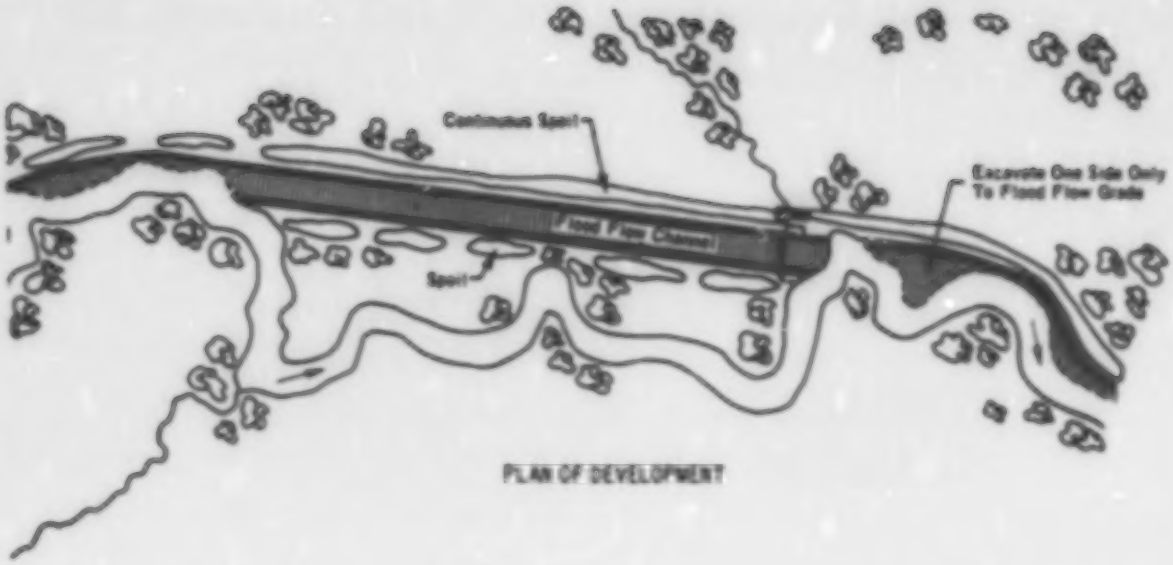
FLOODWAY CHANNELS

Floodways are usually wide artificial channels constructed to carry floodwaters that exceed the capacity of natural river channels. As such, these are invariably unlined, and the bottom elevation is at or close to the natural ground surface level.

The effect of most such channels on ground water quality is minimal, particularly as they typically carry water for only a small fraction of each year. If anything, floodwater flowing in a bypass channel and infiltrating into the ground would tend to improve the local ground water quality.

Because of the negligible effect in degrading ground water quality, no specific control measures are suggested to prevent pollution of this resource.

The effect on surface water quality depends on channel stability measures incorporated into the design of the floodway and the maintenance provided. Incorporation of proper replanting and rip-rapping of channel bends prevents the scour of sediment during high flow periods (Figure 3). Insufficient maintenance can lead to the production of



PLAN OF DEVELOPMENT

(Adapted from Tech. Release No. 25,
Soil Conservation Service, USDA, 1971)

UNDISTURBED STREAM CHANNEL & SEPARATE FLOOD FLOW CHANNEL

Figure 3 Undisturbed Stream Channel and Separate Flood Flow Channel

substantial quantitities of sediment and debris which decreases water quality downstream.

RETARDING BASINS

These basins are constructed on tributary streams and in the main stream. By regulating the hydrograph downstream, flood stages are reduced and damages due to flooding consequently reduced.

Water quality is generally unchanged by these basins during low flow conditions as the water passes through essentially without alteration or retention. During the high runoff periods, the basins help reduce sediment concentrations and trap debris. If accumulated sediment and debris are not removed during maintenance operations, sediment storage will be filled and any additional quantities will be transported downstream.

Proper stabilization, planting programs and the use of sediment trap ponds help alleviate erosion and subsequent input of sediment directly into the basin and prevent caving and slumping of the inundated areas during high water.

LAND TREATMENT MEASURES TO CONTROL POLLUTANT CONTRIBUTION

Land treatment measures include proper land use management techniques and the use of erosion-controlling vegetation in the drainage basin. These measures are effective in reducing sediment-bearing runoff and extending the time for runoff itself during light and moderate rainfall periods but are not particularly effective during heavy rains that lead to flooding. Where bottomlands are cultivated and raw crops are placed adjacent to a channelized stream, it is frequently advisable to leave a filter strip of grass or shrubs along the stream to remove silt and to prevent erosion of the channel banks by field runoff. Basically these measures are beneficial and do not require abatement measures.

FLOOD PROOFING

Flood damage can be avoided by structural modification of buildings in the flood plain. The modifications used include reinforcing of foundations to resist the forces of flood water and the temporary weakening of supporting soil, sealing of windows located at lower elevations than the expected flood water level, and providing for water-tight closure of doors. Other measures recommended entail the moving of appliances, inventories and other valuable materials to the upper stories of buildings so as to be above expected flood water levels. Flood proofing is most effective for new construction as the required modifications can be expensive for older structures.

Non-Structural Alternatives to Channelization

The principal purpose of channelization projects is to reduce the damage caused by periodic flooding. Thus far in this report, the physical methods to mitigate the water quality degradation that occurs because of such channel modification have been discussed. One alternative to a physical solution to prevent damage from flooding is to delineate areas subject to flooding and prohibit uses of

these areas that are damaged by floods. Such non-structural alternatives can eliminate the pollution effects directly attributable to channel modification and if properly planned and enforced can eliminate pollution effects that would otherwise occur when the project design flood is exceeded and flooding occurs.

The CEQ Report (Ref. 1) summarizes these approaches as follows:

"Non-structural adjustments take many forms. The three major measures are regulatory, technical/administrative/ policy, and economic/financial measures. Powers, programs and incentives are available for each. Regulatory measures combine State encroachment statutes, local rural and urban zoning ordinances, subdivision regulations, building and housing codes, and open space regulations. Technical/administrative/policy measures combine flood proofing, temporary (preplanned) and permanent evacuation, flood forecasting and warning systems, alternative uses of protective works, leasing policies, local facilities development policies, urban renewal, and relief and rehabilitation policies and programs. Economic/financial measures combine flood-risk insurance, tax adjustments,

tax adjustments, rights, easements, dedications, reservations and public or private acquisitions."

In practice, a combination of the structural and non-structural approach is taken to reduce flood damage. For any given situation, the effects of the alternatives on water quality should be calculated and considered in the overall project evaluation.

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III. Guidance for the Identification and Evaluation of Impoundments

Introduction

This discussion of impoundments will describe the effects on water quality of both storage impoundments and run-of-the-river or main stream impoundments. In addition to distinguishing between these two classes of reservoirs, the principal difference between lakes and impoundments is discussed.

For many purposes a reservoir may be considered as the upstream half of a natural lake with the dam replacing the downstream half. Since both lakes and reservoirs are physically similar many of the characteristics of lakes are reproduced in reservoirs. There are two significant differences however which produce differences in water quality in downstream discharges.

The first difference involves facilities for controlling the rate of discharge. Downstream flows may be reduced to less than natural by controlled releases from reservoirs and in fact, in certain type operations may be

reduced to zero for significant periods during the daily operating cycle.

The second difference is the depth from which reservoir discharges are withdrawn when compared with the surface discharges from lakes. Natural lake discharges are generally surface waters which are aerobic and therefore have been subjected to the normal aerobic processes of natural purification. Water temperatures of these flows reflect the prevailing average ambient air temperatures. Reservoir discharges are frequently withdrawn from deep within the reservoir. If the reservoir is stratified, this water may be anaerobic and contain undesirable minerals resulting in decreased water quality. Water temperatures may be substantially less than ambient air temperature reflecting the temperature of the winter and spring runoff that was stored.

Run-of-the-river impoundments are located on main stream rivers and are characterized by relatively low head dams with impounded waters not extending far from the natural channel and water detention times of a few days. Water velocities are appreciable and in a positive downstream direction. Passage of water through the reservoir is by displacement usually without significant

vertical stratification other than that caused by daily surface warming by the sun. These impoundments are constructed principally to deepen rivers for navigation in canalization projects or to provide regulation downstream from storage reservoirs operated for power generation.

Storage reservoirs are generally located on tributary streams and are characterized as being relatively deep with the water surface extending far beyond the natural river channel. These reservoirs have large storage capacity in relation to the drainage area and generally have several months detention time. Because of the operation of these reservoirs passage of water through the reservoir may be discontinuous and subject the reservoir to large differences in water level on a seasonal basis. Because of the large lake level fluctuation, past designs have placed outlets deep in the reservoir. These reservoirs are characterized by thermal stratification generally of the classic three layer system during the summer warm weather periods. Primary uses of storage reservoirs include flood storage, hydroelectric power production and water supply storage. Recreational use is an important secondary use on many storage reservoirs.

Current Governmental Involvement

Several Federal agencies are involved in the construction of storage and main stream impoundments. As the principal agency responsible for navigation and flood control on the nation's inland waters, the Corps of Engineers constructs both storage and mainstream reservoirs. The Tennessee Valley Authority is also authorized by the Tennessee Valley Authority Act to construct dams and reservoirs on the Tennessee River and its tributaries for navigation, flood control and power production. The Bureau of Reclamation has constructed storage impoundments to provide water for the irrigation projects in the western States. The Soil Conservation Service constructs impoundments in cooperation with State and local agencies for flood prevention, conservation, development, utilization and disposal of water purposes. The Federal Power Commission is responsible for approving non-Federal development of hydropower and is involved in the approval of impoundment construction for this purpose. Information on reservoir projects for hydropower production of a regional nature is also available from other U. S. Department of Interior agencies including the Bonneville Power Administration, Alaska Power Administration, Southeastern Power Administration and the Southwestern Power

Administration. The Department of Housing and Urban Development has information on reservoirs constructed in housing projects in which they have an interest. State and local governmental agencies are also involved in reservoir construction. Such developments may include recreation reservoirs and public water supply reservoirs. The name of the appropriate State and local agency varies from State to State and therefore must be determined for each particular situation.

Private development of small impoundments has become commonplace. Private developers construct suburban housing developments and recreational weekend communities surrounding man-constructed impoundments. Private development of small lakes has also occurred in conjunction with campgrounds, recreational parks and even pay fishing lakes.

A survey of the governmental sources will delineate the large projects and most of the significant smaller projects. Other projects may require an examination of local construction permit files or consultation with local planning commissions.

Current Practices

Current planning and justification for large reservoirs involving the Federal Government are generally based on multipurpose use. The principal multipurpose uses included are flood control, hydroelectric power production, navigation, recreation, irrigation water supply, public water supply, low flow augmentation for water quality or other special purposes, and fish and wildlife propagation. State and local projects are also generally multipurpose with the exception that some water supply impoundments are reserved solely for that purpose.

FLOOD CONTROL

An extensive network of reservoirs has been constructed for flood control by the Corps of Engineers and the Tennessee Valley Authority. The basic theory of operation of these reservoirs is to reduce storage quantities to a minimum level prior to the normally wet seasons of the year. During the wet season, outlet flows are kept to a minimum while excess tributary flow is stored. Following the wet periods the reservoirs are usually filled to near maximum storage levels. The available storage is then used to maintain normal or increased stream flows, produce

hydroelectric power when passing through the dam, and provide recreational opportunities on the reservoir itself. During the drier periods of the year the level is gradually lowered to reach the minimum as the next wet period approaches.

POWER PRODUCTION

Water storage for power production is one of the oldest uses of reservoirs. Many small reservoirs have been constructed to furnish energy to individual mills or small communities. Presently designed developments are rarely for single purpose hydroelectric power production but the incorporation of this feature is primary at many reservoir sites.

Hydroelectric power production is generally used to meet peak daily loads in conjunction with a steam-electric facility which supplies the base electric power requirements. The steam-electric facilities operate continuously while the hydroelectric power is produced for 4-8 hours to meet peak demands for air conditioning in the summer and heating in the winter, and other home and industrial electric consumption demands. Such peaking power

operations are the standard operating scheme for many areas including that served by the Tennessee Valley Authority.

Some storage reservoirs were constructed sufficiently large in comparison with the power demands of the times to allow continuous power production operations by adjusting water turbine operations to conform to the applied load. This type operation is generally inefficient with greater economies achieved by using steam generated power for the base load and meeting peaks with hydroelectric power.

Many of the main stream impoundments also have power generating facilities. Since the operation of these reservoirs is frequently for maintenance of a specific pool elevation, peaking power with its inherent rapid pool stage fluctuations is not possible. Power production is therefore limited by the incoming river flow and must be marketed on that basis.

NAVIGATION

Development of navigation on the nation's inland waterways is a major use of main stream impoundments. Such dams are serially located along a stream with the pool of the downstream reservoir terminating at the toe of the next

upstream dam. Navigation locks are provided at each dam to raise and lower river traffic. The use of such canalization techniques have been applied on the Ohio River and the Upper Mississippi River to name two examples.

The dams are operated to maintain controlled pool elevations for the convenience of commercial barge traffic. Flow at each dam is adjusted by use of weirs, by flow through the electric generating turbines, and by the number of lockages to maintain the specified pool elevation.

WATER SUPPLY STORAGE

Water supply storage reservoirs include those reservoirs constructed to supply storage for public water supply, industrial water supply and irrigation water supply. Single purpose domestic and industrial water supply reservoirs are frequently small when compared with other types of storage reservoirs. These impoundments are constructed to provide sufficient quantities of water to augment the incoming stream flows during low flow periods. Sufficient detention time is generally provided to allow natural purification processes such as biochemical oxidation of organics and sedimentation of particulate material to enhance the water quality and reduce water treatment costs.

Storage of water for subsequent irrigation use is responsible for most of the agriculture in the western States. Large impoundments, exemplified by the reservoirs on the Colorado River, store water from snow melt and winter rains and provide irrigation water during the growing season. Huge complexes of irrigated farms have been developed to make use of the water which is diverted from these reservoirs.

MULTI-PURPOSE RESERVOIRS

Only infrequently are truly single purpose reservoirs constructed under presently existing conditions. Most reservoirs include many uses although one use may predominate.

Modern planning incorporates multiple uses to calculate the benefits accruing from a proposed project. Costs are likewise allocated to various projected uses. The final benefit-cost ratio reflects the total value of the project as against the cost of construction.

Sources of Pollution

The construction of reservoirs of all types produces direct and indirect changes on water quality of the inflowing water. Direct changes include the physical, biological and chemical alterations that occur during storage and because of the changed environment from that of a moving stream to a quiescent lake. Many of the direct changes to water that occur during storage improve the quality especially in the aerobic surface layers. Through the processes of natural purification objectionable constituents may be removed.

Indirect effects include watershed development which contribute pollutants and nutrients which may ultimately degrade water quality in the impoundment. Frequently the direct changes that occur are also either magnified or mitigated by the changed environment from stream to reservoir.

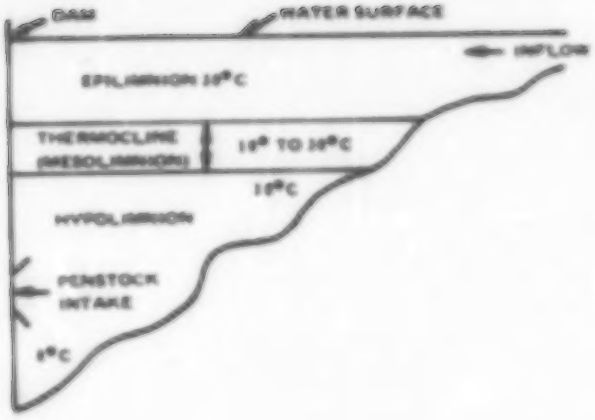
BASIC RESERVOIR HYDRAULICS

The deleterious effects on water quality caused by the construction of a reservoir or by a series of reservoirs in a canalization project can best be understood after an

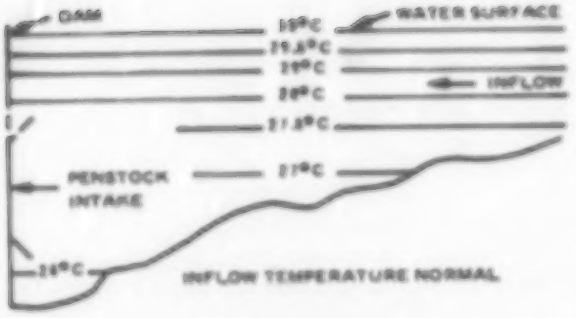
elementary understanding is acquired of basic reservoir hydraulics.

Storage reservoirs in temperate climates frequently become stratified during the summer and winter with periods of non-stratification occurring during the spring and fall. The formation of stable stratification depends on the density of water. The density of water changes with varied temperatures reaching a maximum at 4 degrees Celsius and decreasing with either an increase or decrease in temperature from that point.

The classic stratification pattern for summer has a surface layer, the epilimnion, which is well mixed by wind and wave action. Beneath the epilimnion is a narrow zone of rapid temperature decline called the thermocline or mesolimnion, which is characterized by a temperature change of more than 1 degree Celsius per meter. The lowest zone, the hypolimnion, is effectively shut-off from atmospheric reaeration, and has only a small temperature gradient. The summer stratification is graphically illustrated in Figure 4(a).



a) Storage Impoundment



b) Run-of-the-river Impoundment

Figure 4 Thermal Stratification in Reservoirs During Summer Period

The winter stratification of storage reservoirs is characterized by either ice or water of temperature less than 4 degrees Celsius floating on water of 4 degrees Celsius which then extends to the bottom of the reservoir. The hypolimnion is again stable and is effectively removed from atmospheric reaeration. Because of low temperatures however biological activity is low and water quality may not be substantially impaired during the winter stratification. The winter stratification is graphically illustrated in Figure 5.

The point of discharge in most storage reservoirs is near the bottom so that releases can continue to occur when the water level is low in the reservoir. Thus, hypolimnetic water is generally released. If anaerobic, this water may be initially of poor quality because of no dissolved oxygen, concentrations of odorous constituents and concentrations of soluble metals. The quality of the discharged water is therefore greatly affected by the dissolved oxygen concentration in the hypolimnion if withdrawal is effected from this water mass.

If the dam is constructed so that water can be withdrawn from different depths, stratification allows the selective withdrawal of water of better quality. Selective withdrawal is accomplished through the phenomenon of stratified flow.

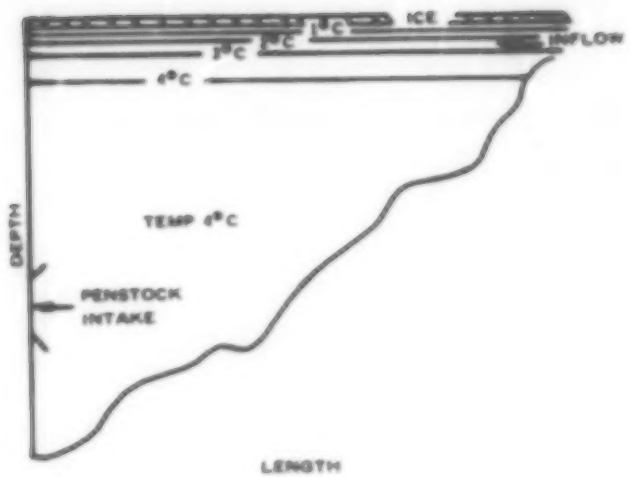


Figure 5 Thermal Stratification in Storage Reservoir During Winter Period

The thermal stratification of storage reservoirs is governed by a heat balance taking into account solar radiation, surface losses by evaporation and conduction, and the input and outputs of heat by inflows and outflows. The thermal stratification effects discussed has a dominant influence on internal flow patterns in the reservoir and greatly affects outflow water quality.

Main stream reservoirs may exhibit a gradual temperature gradient with temperatures decreasing from top to bottom. This gradient is caused by the absorption of the sun's energy in the upper water layers and the existence of insufficient downstream velocity or wind induced mixing to insure complete vertical uniformity. Such a thermal condition is graphically illustrated in Figure 4(b). If the stratification is stable enough to continue overnight or exist for several consecutive days, water quality in the lower layers may be adversely affected by declining dissolved oxygen levels. Downstream quality may be affected depending on the methods of releasing water and location of outlet works at the dam.

To summarize, thermal stratification of reservoirs occurs in both those designed for long term storage and in main stream reservoirs. The effect is to reduce vertical

circulation and the transport of dissolved oxygen to lower layers in the impoundment. Without some means to discharge waters from other than the hypolimnion, downstream water quality may be impaired.

WATER QUALITY CHANGES WITHIN RESERVOIRS

Chemical - Physical Changes

The annual cycle of storage impoundments in temperate climates consists of the winter and summer periods of stratification which are separated by periods of essentially uniform temperature distributions from top to bottom of the reservoir during which the waters freely mix. The periods of mixing are called the spring and fall turnovers. During the turnover periods soluble material entrapped in the hypolimnion is returned to the biologically active near-surface region. The source of this material is water inflows, production in the epilimnion, or leaching from the bottom muds. Such materials consist of the inorganic nutrients nitrogen and phosphorus, chemically-reduced heavy metals such as iron and manganese, and unoxidized organic material. The nutrients become available to support renewed primary production. The turnover period frequently

coincides with the typical fall and spring plankton blooms observed in many reservoirs.

During the turnover periods dissolved oxygen concentrations are uniform throughout the depth of the reservoir. As the reservoir warms following the spring overturn and stratification occurs, the supply of oxygen to the hypolimnion from atmospheric reaeration is terminated. As the summer progresses dissolved organic material in the hypolimnion which includes that present initially plus material settling into and diffusing from the upper layers, exert oxygen demands as bacteria oxidize these materials. If the organic content is sufficient to cause total depletion of dissolved oxygen concentrations then anaerobic conditions become established and water quality is seriously degraded.

Compounds such as metallic phosphates and carbonates which are chemically stable and insoluble under aerobic conditions become soluble and enter solution under anaerobic conditions. This condition leads to the leaching of materials from the bottom muds. The bottom muds have an oxidized surface layer during aerobic conditions which prevents leaching of underlying anaerobic products. Under anaerobic conditions this oxidized zone is eliminated and

compounds are readily leached. Increases in iron, ammonia, manganese, silica, phosphate and sulfide ions have been observed in oxygen depleted waters in contact with bottom muds. Increases in soluble organic compounds also occur.

Since many storage reservoirs withdraw water for release from near the reservoir bottom, the quality of this water may be much poorer than that which occurred in the pre-impoundment stream. Low dissolved oxygen concentrations, the presence of reduced metallic compounds and the presence of odorous organic compounds are evidence of such deterioration.

Main stream reservoirs as a general rule do not become stratified for extended periods of time. Depending on the dissolved oxygen concentration gradient (if one exists) similar leaching from the bottom muds as that in storage reservoirs may occur. Without stratification and assuming mixing from top to bottom, the water discharged does not represent a particular zone and thus the depth of withdrawal is not critical to water quality.

Biological Changes

In the process of converting a stream into a reservoir the biological community must adapt from a moving water stream system to a still water or lake environment. The entire biological system may change significantly in storage reservoirs whereas only minor changes may occur in main stream reservoirs. Anticipated changes include population shifts in plankton, rooted aquatic plants, aquatic invertebrates, and fish.

SITE PREPARATION EFFECTS ON WATER QUALITY

Water quality may be affected by many characteristics of the reservoir location site. Factors which affect future water quality include maximum and operating depth range, reservoir configuration, relation of principal axis to prevailing wind direction, geology of area, characteristics of the underlying soil, and the type of native vegetation.

The characteristics of the underlying soil and the vegetation that remain before inundation are important to future reservoir water quality. Both the soils and vegetation require investigation to determine the amount of organics present in the soil and its state of decay so that

the amount of leachable color, nutrient release, organic acid production and decrease in pH can be predicted. Additional soil analyses can determine the amount of leachable inorganic salts present which tend to increase the total dissolved solids in the overlying water. Based on such determinations, decisions can be made regarding the necessity of removing organic soils prior to inundation or using a mineral soil covering of the organic soils to prevent their undesirable effects.

The chemical, physical and biological reactions that occur at the soil-water interface are complex and not particularly well understood. It has been shown however that these reactions are more of a biochemical nature than purely chemical or physical. The organic content of the soil and pre-inundation vegetative cover are responsible more than other characteristics for the undesirable effects on the overlying water. The adverse effects caused originally by freshly inundated soils are reduced with time. This aging process is a combination of leaching, of organic destruction and of being covered by sediment transported into the reservoir. Estimates of the time required for reservoir bottoms to stabilize so that tastes, odors and color are not imparted to the water indicate that 10-15 years may elapse. The equilibrium condition is defined as

into a sufficient volume of water surrounded by a silt barrier. The spoil would then be subjected to prolonged aeration in an effort to satisfy the associated oxygen demand. It is conceivable that aeration could be followed by coagulation. If this system proves practical, dredging could be used to both improve the area from which the material was removed by removing unwanted organic substances and improving overall water quality by satisfying the oxygen demand associated with organic material. Aeration offers the potential to deal with highly polluted spoil in a progressive, environmentally compatible manner.

Aeration of bays, harbors, and other areas has been suggested as a possible method of treatment where organic sludges are responsible for noxious anaerobic conditions. The method, if ultimately proven practicable, could result in changeover from anaerobic to aerobic decomposition and conceivably modify long-term ecologically undesirable and aesthetically displeasing conditions. Effectiveness of such techniques may be enhanced if combined with the selective removal of organic bottom sediments by dredging.

CHEMICAL TREATMENT

Chemicals such as oxidants, flocculants, and non-wetting agents may improve dredged materials during or subsequent to dredging and disposal operations. Chemical treatment methods are currently under investigation.

DISPOSAL TREATMENT

Dredged material may also be treated before being redeposited. Such treatment would not effect the dredged site, but could possibly aid in improving the deposition area.

Suggested methods all of which have had limited application in treating dredged material before redeposition include:

Flocculation

Flocculation within a diked disposal area has been successful in speeding the natural sedimentation process and thus clarifying the resultant effluent. However, this technique requires fairly quiescent water, maximum settling prior to addition of chemicals, and efficient mixing. A

suggested open water disposal practice would utilize a silt barrier to enclose a "treatment area" in which dredged material could be deposited.

After an initial settling period flocculants would be applied. This method holds promise of limiting possible undesirable effects of dredged material disposal.

Incineration

Much as in municipal and industrial waste treatment, the treatment of highly organic dredged material requires handling of a solid and liquid phase. Incineration is a proven technique that can be expected to handle organic solids and may be applicable to highly organic dredged material. Sludge with a sufficiently high volatile solids content occurs in a number of harbor areas. The sludge would require preliminary dewatering through settling, vacuum filtration, or some other technique before incineration. Other proposed stabilization techniques include wet oxidation and fluid bed incineration. Air pollution must be controlled in all cases.

Filtration

The use of filters of various types is a possibility. If the spoil contains a sufficient percentage of sand, gravel, or other large particles, a screening or centrifuge process can perform fairly efficient water-solids separation. In the case of finer materials, sand bed filters, as used in municipal water treatment plants, could possibly find application in effluent treatment. Such filters could be built as integral parts of a diked area.

Since the spoil placed in a confined disposal area may often be physically similar to domestic sewage sludge, the use of vacuum filters for initial dewatering appears possible. In this manner, the sludge could be separated out for eventual inland disposal (by other means such as rail or road haul). The disposal area could be regarded as a treatment plant, the larger solids being separated by vacuum filters and the liquid effluent being treated by other processes. Pretreatment by coagulant aids such as long-chain polymers, or alum, would probably be necessary to aid the dewatering process.

Sewage Treatment Plants

Disposal of highly organic dredged material from waterways into a waste water treatment plant may be practical in some cases, but is expensive and requires long periods of time to dispose of large quantities of solids. The nature and volume of the material would normally overwhelm the capacity of a typical treatment facility. A major limitation of this system is the requirement that dredging operations cease during periods of high sewage flow, such as those following a rainstorm. The scheme would be unworkable in large dredging projects, but may be a viable alternative in small projects, particularly if temporary storage facilities are available to hold the material for further processing.

Dredged Material Disposal Techniques

Dredged material can be disposed of on land, in estuaries or in open water. Some of the adverse effects can be mitigated or ameliorated by proper disposal site selection to minimize ecological effects. Additionally, modified dredging techniques or the use of peripheral equipment designed to reduce spoil losses can also reduce adverse effects.

OPEN WATER DISPOSAL

The Environmental Protection Agency has published guidelines for disposal in the oceans (16 May 1973 Federal Register) and will establish guidelines for the navigable waters under Section 404 of Public Law 92-500. The discussion here is of a general nature and not meant to supplant these activities. Short-term effects of open water disposal of dredged material on the benthic biological community included destruction of less mobile forms whereas some types were able to surface and survive. High turbidity associated with spoil disposal apparently had little direct effect on organism mortality.

Methods designed to minimize the effects of dredged material disposal include: investigation of current dispersal patterns before site selection, benthic community surveys and the accurate placement of dredge spoil.

If the spoil contains pollutants, estimates of the impact of oxygen demands created or the release of toxic compounds must be made before disposal. Site selection or the use of alternative disposal methods will be influenced by the nature and presence of these pollutants.

LAND DISPOSAL

Land disposal is defined as disposal neither in open water nor on marsh land. It includes disposal on upland areas or on bars or islands. Such areas may be confined by dikes or natural barriers or may be unconfined. Confined areas are usually equipped with spillways or overflow weirs and occasionally with settling basins.

Dikes may be constructed of incompetent material and in these instances careful design is required to prevent failure. Dikes have breeched on numerous occasions causing extensive losses of spoil. In some instances dikes may be pervious and permit seepage through and beneath the structure. Ground water contamination adjacent to and beneath the disposal area may occur. If such contamination is likely, the use of liners or other impervious materials may be required.

Methods of improvement and utilization have been developed to minimize the effects of dredged material disposal. The spoil often contains a significant percentage of fine grained organic constituents and high water content. Such materials are generally ill-suited for foundations. Improvement of structural properties can be accomplished by

dewatering and compacting. Dredged material drains very slowly because the dikes foster perched water tables and water retention.

Several methods have been incorporated into projects to improve the structural properties of the material:

Ditching - The water table can be lowered by ditches which also provide drainage of surface runoff. Removal of the water also promotes consolidation.

Sand Drains - The vertical sand drain is a cylindrical column of sand or granular material placed in a vertical hole and connected at the original surface with a drainage blanket. These drains provide an avenue of escape for pore water and promote consolidation.

Ground Surface Drains - This method requires that the disposal site be initially covered by a layer of sand before applying dredged material. The horizontal sand "blanket" provides a permanent drain for overlying water and promotes consolidation.

Experimental projects have suggested the possible use of vacuum wells, electroosmosis and dessication for

dewatering dredged material. Additional research and testing will be required to evaluate these techniques.

MARSHLAND DISPOSAL

Marshland disposal has been common in the past because of accessibility and the inexpensive value of the land. Because of the increasing expense of other land resulting from development of coastal areas, these marshlands were frequently the only land disposal sites available.

Disposal of dredged material on marshes and wetlands is contrary to existing Environmental Protection Agency policy. The Environmental Protection Agency's policy statement on protection of the Nation's wetlands appeared in the Federal Register, Volume 38, Number 84 Wednesday, May 2, 1973. The policy statement is aimed at preservation and protection of the wetland ecosystems from destruction by waste water or nonpoint source discharges. The policy makes specific reference to the necessity "...to protect wetlands from adverse dredging or filling practices..."

Productive Uses of Spoil

Rather than being considered detrimental, spoil can be used advantageously under certain circumstances. Potentially beneficial uses are outlined below.

ARTIFICIAL WILDLIFE HABITAT CREATION

Among the most promising artificial habitat creation schemes using dredged material is the dredged-material island and the creation of marshes. Artificially created dredged-material islands may be naturally colonized by indigenous terrestrial vegetation or specialized waterfowl feed plants can be introduced. Small lakes may be created for fish and wildlife habitats within the disposal area.

Careful spoil placement and recolonization of marsh vegetation is required. Since many of the nation's marshes have been destroyed by previous dredging operations and other of man's activities, the creation of new marshes in such areas is desirable to restore or replace the ecological nursery and habitat for fish and wildlife.

Another possible artificial habitat is the development of shellfish beds in open coastal water areas. Whole

ecosystem habitats can possibly be re-created in conjunction with dredged material islands and artificial marshlands. These methods must be evaluated as to their possible effect on existing ecosystems.

LAND DEVELOPMENT

Land environments adjacent to the oceans, estuaries and major streams offer valuable sites for commercial, industrial and recreational development. Dredged material disposal practices in these areas can be very useful if properly managed.

Dredged material landfill can be directed to the development of recreational areas to the benefit of man. The use of life-supporting "top" material on a spoil fill will encourage rapid development of terrestrial vegetation.

Land created by dredge material disposal has historically been used in harbor development and for other construction whether deliberately placed or fortuitously located. Piers, access roads and commercial and industrial structures have been constructed on dredged spoil material.

Special materials such as sand which have good drainage and competent structural properties should be used where construction is anticipated. Since these materials are generally not polluted to a significant degree, the drainage and runoff ordinarily cause minimal environmental effects. However, these projects generally do not assist in the disposal of material from maintenance dredging which may contain a high percentage of silts and clays. Treatment methods would be required to use these materials in fills where construction is anticipated.

The use of maintenance dredging materials, often organically polluted, also creates the possibility of ground water pollution. Unless the material is appropriately treated or the drainage adequately controlled, percolating waters may convey leached pollutants from the fill into the underlying ground waters.

AGRICULTURAL LAND USE

Isolated studies have been made on the application of organically rich dredged material to agricultural lands using methodology similar to that developed for applying sewage sludge to the land. Careful material selection is required so that damage may be avoided. Application of

clay-silt dredged material to sandy soils may improve moisture holding, ion exchange, and textural characteristics. Improper application could reduce drainability.

Agricultural use of marine dredged material generally is not possible inasmuch as the high salinity level of the material may be lethal to plant life. Also, leaching of marine material may seriously impair ground water quality.

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